

REMARKS:

The present Amendment makes editorial changes in the title, specification and claims, and adds an Abstract to conform the present PCT application to the requirements of United States patent practice. The
5 cancellation of claims 1-12 in favor of the claims presented herein has been done solely because the amount of strikethroughs and underlining in original claims 1-12 that would have been necessary to confirm those claims to the requirements of United States patent practice would have been unduly burdensome and confusing. No change in the claim language has been
10 made for the purpose of distinguishing any of the present claims over the teachings of the prior art of record. Accordingly, no difference in the claim language between the present claims and original claims 1-12 is considered by the Applicants as a surrender of any of the subject matter encompassed within the scope of original claims 1-12.

15 Early consideration of the application on the merits is respectfully requested.

Submitted by,

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MARKED-UP COPYDescription

MRI MAGNET DEVICE WITH AXIALLY ADJUSTABLE ROSE SHIM RING

(1) Technical field

SPECIFICATION

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TITLE

"SHIMMING STRUCTURE AND METHOD FOR A MAGNETIC RESONANCE
IMAGING APPARATUS"

BACKGROUND OF THE INVENTIONField of the Invention

10 The present invention relates to a method of for adjusting the static magnetic field in the a magnetic resonance imaging (MRI) device or Nuclear Magnetic Resonance (NMR) device and a static magnetic field generating apparatus that could generate generates a higher field strength. The principle of the present invention can be used in will be illustrated by taking a C-type magnet
15 in the of a magnetic resonance imaging apparatus equipment as an example, but the present invention is not only applicable to magnetic resonance magnet, but also to nuclear magnetic resonance magnet and suitable for use in other devices using an electro-magnet to generate a uniform static magnetic field and the shape of the magnet is also not limited, without limitation to the exemplified C-type.

20 (2) Background Art

Description of the Prior Art

In the early days when the permanent magnet is used in development of magnetic resonance imaging equipment for commercial use, the field strength of the permanent magnet was usually lower than 0.25T. In the 1990's, magnetic resonance imaging equipment for commercial use were developed that employ employed a permanent magnet appeared with a field strength of 0.3T and the performance thereof was better, the cost was reasonable and the structure was compact. The greater the field strength is, the higher the signal-to-noise ratio is,

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and the better the quality of the image generated by the permanent magnet magnetic resonance equipment. In recent years, the field strength of some of the permanent magnets ~~could even~~ can reach 0.35T-0.4T.

At present, some certain problems exist in the manufacturing of a magnet

5 with a higher field strength, they are such as:

I. Permanent magnets having a field strength greater than 0.3T and with high homogeneous magnetic field in the scanning area are expensive, large in volume and heavy in weight (heavier than 17 tons) and need a large area for installation, and thus these defects have limited its application in the

10 magnetic resonance equipment.

II. Since a uniform strong magnetic field is to be generated, the size of the pole plates are usually is large, thus the open angle between the two pole plates will inevitably be limited and this is a problem for patients of subject to claustrophobia.

15 III. The magnet needs shimming or repairing during its installation and use, or re-shimming is required when service and thus the gradient coil and transmitting coil have to be removed, which is time-consuming and expensive.

IV. Due to manufacturing tolerances, magnets of the same design may have different field strengths strength, thus volume production of the same RF coils and the systems become becomes very difficult and thereby the costs for the corresponding system of the whole magnetic resonance equipment increase.

With respect to To address the above problems, the following methods are
25 conventionally usually employed:

I. In order to To increase the field strength and improve the field homogeneity uniformity thereof, the method generally adopted is to increase but this increases the volume and size of both the permanent magnet and the pole

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plate, which will increase the cost as well as the volume and weight of the magnet.

- II. The uniformity homogeneity of the magnetic field is improved by employing a Rose ring but when the field strength is over 0.3T, the magnetic field uniformity homogeneity of the permanent ~~for the obtaining~~ a magnetic resonance image of the whole human body becomes worse and a single Rose ring cannot ensure the uniformity homogeneity of the field strength.
- 5
- III. Permanent magnets that could reduce magnetic flux leakage are employed to compensate for the field strength leakage in the external edge of the pole plate, but ~~said method~~ this increases the size of the external edge of the magnet pole plate and reduces the open angle between the pole plates, and meanwhile, it furthermore requires complicated manufacturing process and hence increases the cost.
- 10
- IV. Field strength adjusting and fine adjusting structures are employed, but these mechanisms are complex in designs design and expensive.
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Moreover, the effects achieved by all of these known methods ~~in the prior art~~ are still not satisfactory.

(3) Contents of the invention

SUMMARY OF THE INVENTION

- 20 Therefore, ~~the~~ The method and apparatus ~~is of~~ of the present invention adopts employ the following measures features to overcome the technical defects existing forementioned disadvantages in the prior art.
- I. Employing another adjusting shimming ring (the second type of Rose ring) without increasing the size of the pole plate to improve the uniformity of the magnetic field while not reducing the open angle between the pole plates.
- 25 Meanwhile, ~~said~~ The additional shimming ring (the second type of Rose

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ring) has a variable distance with respect to the first type of Rose ring so as to change the magnetic path and adjust the uniformity of the magnetic field.

II. Distribute permanent magnetic materials having different magnetic energy levels in special manners so as to improve the uniformity homogeneity of 5 the magnetic field and reduce the cost.

III. Three methods are employed in the present invention to adjust the magnetic field strength and shimming. One is adjusting and shimming the static magnetic field by fine adjusting magnetic conducting bars or permanent magnetic bars installed on the external edge of the pole plate for example of the C-type magnet, so as to compensate for the 10 inhomogeneous magnetic field caused by tolerances of magnet manufacturing and assembling; another is providing a magnetic conducting or permanent magnet bolt adjusting mechanism on the shimming Rose ring, and the magnetic path is changed by adjusting the position of the bolt 15 so as to adjust the magnetic field; the other method is changing the magnetic path by changing the position of the second type of shimming ring with respect to the first type of Rose ring as mentioned in method one, and thereby ~~to adjust~~ adjusting the magnetic field. The joint combined 20 application of said these three methods will achieve a large range of adjustment and is easy in operation. Hence, the inhomogeneity caused by the tolerances of manufacturing and assembling is compensated and the field strength of the permanent magnet is made uniform.

Further, the method and apparatus of the present invention use the above-mentioned two or three methods jointly to achieve better shimming effect.

In the prior art, the Rose shimming ring (5) is provided at the external edges on the horizontal plane of the pole plates of both the upper and lower poles, but the shimming effect achieved by a single pair of shimming rings is not satisfactory. Due to the characteristics of the structure of the permanent magnet, the magnetic field strength at the edge of the pole plate is relatively weak, which is 25

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especially serious when the field strength is over 0.3T, thus single shimming ring cannot fully compensate the inhomogeneity of the magnetic field. The present invention improves the design and fixing manner of the gradient coil and the transmitting coil. Taking the upper pole plate shimming ring as an example, an
5 additional shimming ring (the second type of Rose ring) (6) with adjustable distance to the shimming ring (5) is employed at the external edge of the lower end of the first shimming ring (5) to change the ~~uniformity~~ homogeneity of the magnetic field and a corresponding shimming adjusting mechanism is provided. Similarly, the second type of shimming ring the spacing of which from (6) whose
10 ~~distance with to~~ the first shimming Rose ring (5) is adjustable, is also employed at the corresponding position on the lower pole plate.

~~With respect to the defects To address the aforementioned disadvantages~~ in the prior art, the present invention provides a static magnetic field generating apparatus in the magnetic resonance equipment; it comprises having a permanent
15 magnet magnetic field source (1), and a C-type yoke or a multi-posts multipart supporting structure that constitutes forms the magnetic path. The examination ~~subject measured body~~ is positioned in the space between the two opposite end faces of the permanent magnet magnetic field source (1), ~~wherein the said The~~ two opposite end faces are mirror symmetrical by with respect to the virtual plane
20 between the two faces[[;]]. Pole plates (2) are placed on each of the opposite end faces. The structure is symmetrical with respect to the virtual middle plane but ~~for the illustration purpose, take in~~ the upper half for example, pole pieces (4) are employed disposed beneath the aforementioned pole plate, a gradient coil is employed disposed beneath the pole piece (4), an RF transmitting coil (8) is
25 employed disposed beneath gradient coil (7), a first shimming ring (5) is employed outside the gradient coil. Each (7); each pair of the pole plates (2), pole pieces (4), gradient coils (7), RF transmitting coils (8) and the first shimming rings (5) are substantially mirror symmetrical with respect to the virtual plane between the two opposite end faces. An additional second shimming ring (6) is employed on the
30 external edge of the each of the first shimming rings (5), and the second shimming ring (6) is symmetrical to the above aforementioned virtual plane, to uniform

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homogenize the static magnetic field in the space, occupied by of the measured body examination subject.

According to the static magnetic field generating apparatus of the present invention, the outer faces of the additional upper and lower shimming rings (6) which are facing that force the examination subject do measured body are essentially not projecting higher than project beyond the outer plane of the RF transmitting coils so as to keep maintain the openness of the magnet.

Another solution for the static magnetic field generating apparatus of the present invention is that said to form the magnetic field source is composed of a plural with multiple groups of permanent magnetic columns of different magnetic energy levels, the. This distribution of magnetic energy level of levels in the columns can be axially symmetric with respect to the central axis through the pole center but perpendicular to the pole plane. The distribution of energy level of levels in the columns can also be symmetric with respect to one or more axis in the pole plane through the center point of the pole, for example, the left and right halves, and the front and back halves are symmetrical.

According to In an embodiment of the static magnetic field generating apparatus of the present invention, wherein the permanent magnet magnetic field source is arranged in rings according to the magnetic energy levels. The number of rings could can be two, three or more. For example, when three rings are arranged, said the permanent magnet magnetic field source is divided into three ring areas according to the magnetic energy levels, wherein the magnetic energy level of the external ring area is N3, the magnetic energy level of the middle ring area is N2, and the magnetic energy level of the inner ring area is N1, and N3>N>N1.

Another solution In another embodiment of the static magnetic field generating apparatus of the present invention is providing a plurality a number of magnetically magnetic conducting bolts or permanent permanently magnetic bolts (11) are arranged symmetrically with respect to axes in the pole plane. Those

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adjusting bolts are mounted on one or a plurality more of the parts of the pole plate (2), the permanent magnetic field source (1), the first shimming ring (5) and or the second shimming ring (6), so that the field strength of the static magnetic field is precisely adjusted.

5 In the prior art, the field strength at the edge of the magnet is usually lower than that at the center. Therefore, as a measure in the prior art, adding a first shimming ring (5) to the outer side of the gradient coil will increase the field strength at the edge. However, the inventor of the present application found, but the present invention is based on the finding that only using only a first shimming ring (5) will not achieve satisfactory effect. Hence, as a part of Thus, in accordance with the present invention, a second adjustable shimming ring (6) is added to the side of the first shimming ring (5) that faces the measured body examination subject and to the outer side of the gradient coil (7), and the fixing relation between the gradient coil and the transmitting coil is adjusted. For the 10 volume production of the system, the manufacturing tolerances need to be considered.
15

According to the above-mentioned principle of the present invention, a shimming ring of different shape could be designed to replace the first shimming ring (5) and the second shimming ring (6).

20 In another embodiment aspect, in order to achieve for shimming ef to achieve higher homogeneity, the magnetic field profile has to be re-designed when designing the magnetic source assemblies of different magnetic energy levels. In this process, the factors that influence the field strength of the magnetic field should be considered, for example, manufacturing precision, deviation of the 25 assembling position and even minor corner damage of the magnetic columns in the assembling process.

As a part of the present invention, for the adjusting bolts of ferro-magnetic ferromagnetic or permanent magnetic material, screw threads could be made are provided on many parts of the magnetic field generating apparatus, and the bolts

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are made by of magnetic materials that are the same to as or different from the materials of said the parts. Matching between the screw threads and the bolts is very important, because if they are too tight, a strong force has to be applied to the screw rod during adjustment and thus causing deformation or even break
5 breakage of the bolts, but if they are in too loose contact, due to the vibration caused by the pulse pulsed magnetic force, the will cause the field strength will be made to become unstable and thus causing irregular changes of field strength.

According to the situations of Dependent on the manufacturing conditions, said the additional shimming ring (6), the permanent magnetic field source (1) of
10 different magnetic energy levels, and the adjusting bolts (11) of magnetic material of the present invention could be applied used jointly. For instance, the shimming effect could be achieved by using a second shimming ring (6) in combination with permanent permanently magnetic columns (1) of different magnetic energy levels, or by using the second shimming ring (6) in combination with fine adjustment by
15 magnetic conducting bolts or permanent magnetic bolts (11). Meanwhile, the The shimming effect could also be achieved by adopting permanent magnetic columns (1) of different magnetic energy levels to form the magnetic field profile while combining the method of fine adjustment by magnetic bolts (11).

Or else Alternatively, the shimming effect could also can be achieved by
20 adopting using the second shimming ring (6), the magnetic source composed of permanent magnetic columns (1) of different magnetic energy levels and the fine adjustment by magnetic magnetically conducting bolts or permanent permanently magnetic bolts (11) at the same time.

The present invention also discloses includes a method of for adjusting the static magnetic field in magnetic resonance equipment, said magnetic resonance equipment comprises having a permanent magnet magnetic field source (1), a C-type yoke or a multi-posts multi-post supporting structure that constitutes forms the magnetic path[[;]], with the measured body is examination subject being positioned in the space between the two opposite end faces of the permanent
30 permanently magnetic columns (1), wherein the said. The two opposite end faces

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are mirror symmetrical by with respect to the virtual plane between the two faces[[;]]. Pole plates (2) are placed along the direction of the measured body on each of the opposite end faces; ~~the~~. The structure is symmetrical with respect to the virtual middle plane ~~but for the illustration purpose, take~~. In the upper half for 5 example, pole pieces (4) are employed disposed beneath the aforementioned pole plate, a gradient coil (7) is employed disposed beneath the pole piece (4), an RF transmitting coil (8) is employed disposed beneath the gradient coil (7), a first shimming ring (5) is employed disposed outside the gradient coil (7); each. Each 10 pair of the pole plates (2), pole pieces (4), gradient coils (7), RF transmitting coils (8) and the first shimming rings (5) are substantially mirror symmetrical with respect to the virtual plane between the two opposite end faces, characterized in that: an. An additional second shimming ring (6) is employed disposed on the external edge of the each of the first shimming rings (5), and the. The second shimming ring (6) is symmetrical to the above virtual plane, to uniform 15 homogenize the static magnetic field in the space of the measured body further; further, the permanent magnet magnetic field source is composed of a plural groups of permanent magnetic columns of different magnetic energy levels, so that the magnetic energy level of the permanent magnetic columns further farther from the center of the pole plate is higher than that of the permanent magnetic 20 columns nearer from to the center of the pole plate, and thereby to improve the uniformity homogeneity of the magnetic field; and more further. Further on the basis of the above-mentioned method, a plurality number of magnetic conducting bolts or permanent magnetic bolts (11) are employed symmetrically along the end face axis of the permanent permanently magnetic column (1) on the pole plate (2), 25 or along the permanent permanently magnetic column (1), the first shimming ring (5) and the second shimming ring (6), and by. By adjusting the positions of said the magnetic inducing magnetically conductive bolts or permanent permanently magnetic bolts (11), the field strength of the static magnetic field is adjusted.

Moreover, another Another embodiment of the inventive method of 30 adjusting the static magnetic field in MR equipment, said is applicable to magnetic resonance equipment having a comprises permanent magnetic source (1), and a

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C-type yoke or a multipost multiposts supporting structure that constitutes forms the magnetic path. The measured body examination subject is positioned in the space between the two opposite end faces of the permanent magnetic source (1), wherein the said two opposite end faces are being mirror symmetrical with respect

5 to the virtual plane between the two faces[[;]]. Pole plates (2) are placed disposed on each of the opposite end faces[[;]]. The structure is symmetrical with respect to the virtual middle plane; For the illustration purpose, take. In the upper half for example, pole pieces (4) are employed disposed beneath the afore mentioned aforementioned pole plate, a gradient coil is employed disposed beneath the pole

10 piece (4), an RF transmitting coil (8) is employed disposed beneath the gradient coil (7), a first shimming ring (5) is employed disposed outside the gradient coil (7); each. Each pair of the pole plates (2), pole pieces (4), gradient coils (7), RF transmitting coils (8) and the first shimming rings (5) are substantially mirror symmetrical with respect to the virtual plane between the two opposite end faces;

15 characterized in that : the. The permanent magnetic source (1) is composed of a plural multiple groups of permanent magnetic columns of different magnetic energy levels, so that the magnetic energy level of the permanent magnetic columns further farther from the center of the pole plate is higher than that of the permanent magnetic columns close to the center of the pole plate, and thereby to

20 improve improving the uniformity of the magnetic field, and meanwhile, a plurality. A number of magnetic conducting magnetically conducting bolts or permanent permanently magnetic bolts (11) are employed symmetrically along the end face axis of the permanent magnetic source (1) on one or a plurality more of the parts in the said pole plate (2), permanent magnetic source (1), first shimming ring (5)

25 and the second shimming ring (6), and by adjusting the positions of the said magnetic conducting bolts or permanent magnetic bolts (11), the field strength of the static magnetic field is precisely adjusted aforementioned mirror symmetrical arrangement.

(4) Description of figures

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The five figures of embodiments of the present invention further illustrate the principle of the present invention, wherein:

Fig. 1 shows the shimming rings on the upper and lower poles of the C-type magnet;

5 Fig. 2 shows the enlarged drawing of the part marked in a circle in Fig. 1;

Fig. 3 shows the method of adjusting field strength by using a plurality of magnetic conducting or permanent magnetic bolts;

Figs. 4 and 5 show the method of making the magnetic field more uniform by making different areas of the magnetic field to have different magnetic energy

10 levels.

DESCRIPTION OF THE DRAWINGS

Fig. 1 is a side view of a magnetic resonance imaging apparatus having a C-type magnet, constructed and shimmed in accordance with the principles of the present invention.

15 Fig. 2 is an enlargement of the circled portion of Fig. 1.

Fig. 3 illustrates an embodiment of a method for adjusting (shimming) the magnetic field strength in accordance with the invention, using a number of magnetically conducting or permanently magnetic bolts.

20 Fig. 5 is a side view, partly in section, of a further embodiment of a static magnetic field generator of a magnetic resonance imaging apparatus in accordance with the present invention, wherein the magnet is divided into columns respectively having different magnetic energy levels.

Fig. 5 is a sectional view of the apparatus of Fig. 4, in a plane proceeding perpendicularly to the vertical dot-dash axis shown in Fig. 4.

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DESCRIPTION OF THE PREFERRED EMBODIMENTS

Fig. 1 shows the shimming rings of the upper and lower poles of the a C-type magnet. In Fig. 1, component 9 is the The apparatus has a press plate, component 10 is the and a magnetic field generating source 10, having 5 permanently which comprises the permanent magnetic columns 1 (1). A plurality number of magnetic magnetically conducting or permanent permanently magnetic bolts 11 are movable (11) which could move up and down are shown in the at external edge of the magnetic field source in Fig. 1 so as to achieve the above-mentioned adjustable effect.

10 Fig. 2 is the enlarged drawing is an enlargement of the part portion marked in a circle in Fig. 1, wherein component 1 is showing the permanent magnetic source 1, component 2 is the pole plate 2, component 3 is the pole plate 3 after cutting processing, component 4 is the another pole plate 4, component 5 is the first shimming ring 5, component 6 is the second shimming ring 6 with an 15 adjusting means, component 7 is the gradient coil 7 and component 8 is the RF emitting coil 8. It can be seen from Fig. 2 that a new In accordance with the invention shimming ring (6) is 6 has been added in addition to the original shimming ring 5 (5). In Fig. 2, the outer diameter of the upper shimming ring 5 (5) is the same as that of the lower shimming ring 6 (6). The inner diameter of 20 shimming ring 6 (6) is larger than that of the shimming ring 5 (5), so that the space that is smaller than the inner diameter of shimming ring 6 (6) and that is under the shimming ring 5 can (5) could be used for fixing the gradient coil 7. The lower end face of the shimming ring 6 (6) is does not lower than extend or project 25 below the lower plane of the transmitting coil 8. Similarly, the two shimming rings of the lower pole plate 4 are located at the position that corresponds is corresponding to the position in the upper plate 2, and such design will not reduce so the respective distances between the upper and lower pole plates 2 and 4, as well as between the two shimming rings 5 and 6, are not reduced, i.e., the openness will not be affected. In Fig. 2, two dark black arrows that show 30 movement horizontally and vertically respectively are used to indicate that the

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shimming ring 6 (6) and the bolts mounted on the first shimming ring 5 (5) and the second shimming ring (6) can be adjusted in these two directions.

Careful consideration ~~on as to~~ the size and position of the second shimming ring 6 (6) will help to improve the magnetic field distribution at the edge and enhance the adjusting effect of the shimming, ~~and meanwhile, but~~ the open-space between the upper and lower poles will not be affected.

Fig. 4 shows another method of changing adjusting the uniformity homogeneity of the field strength. Generally, ~~in for a~~ permanent magnet with a field strength ~~ever above~~ 0.3T, the field strength at the edge of the pole plate thereof is weaker than ~~that~~ at the center of the pole plate. In order to make the magnetic field of the area between the two pole plates more uniform, the present invention ~~puts forward a method of dividing~~ inventive method divides the magnetic field generating source into several areas, and magnets at different areas have different magnetic energy levels. As an example shown in Fig. 4, the several ~~circular-shape~~ circular-shaped or ring-shape ring-shaped areas on the pole plate of the present invention that are centered at the axis of the pole plate ~~are made to~~ have different magnetic energy levels, wherein the magnetic energy level in the center area is N1, the magnetic energy in the middle area is N2 and the magnetic energy level in the external area is N3 and $N1 < N2 < N3$. Also, as shown in Fig. 4, a plurality number of magnets of different magnetic energy levels ~~could~~ can be provided in the a symmetrical manner ~~of being symmetrical~~ along the vertical axis through the center of the pole plate.

Fig. 5 is a longitudinal section of the magnet, and the shadows of different gray levels indicate magnet objects of different magnetic energy levels, which are symmetrical along the center of the magnet. The magnetic energy level at the center area is lowest and magnets nearer the external edge have higher magnetic energy levels. Other magnetic energy levels combination forms ~~could~~ can be derived on the basis of the principle of the present invention according to the non-uniform structure intentionally designed on the pole plate and the characteristics of the magnetic path. Magnetic Each magnetic energy level could be further

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divided into a number of sub-levels plurality of levels, and the ordering of the energy level levels is not limited to the manner of increase increasing from the center to the outer edge, and adjustment could be made on the basis of the pole plates and the magnetic path structures of the devices.

5 ~~In addition, as~~ As shown in Fig. 3, another method of uniforming the magnetic energy level of the present invention is to insert a plurality of magnetic bolts at the external edges of the pole plate and the press plate, and the uniformity homogeneity of the field strength is adjusted by changing the magnetic path. As shown in Fig. 3 (and Fig. 1), these magnetic bolts could be arranged
10 symmetrically. However, if the influence of the middle section connecting object of the C-type magnet on the field strength between the two poles or other multi-column plate structures are considered, these bolts could also be arranged in a non-symmetrical way. In the existence of tolerances of manufacturing and assembling of said magnetic resonance imaging equipment, the field strength of
15 the diagnosing area could be adjusted by adjusting these bolts to some extent. The material of the bolts could can be permanent permanently magnetic material or ferromagnetic material and the diameters of the bolts could be either the same or different, but they are preferably the same. The bolts should be arranged symmetrically or near symmetrically, and the number of the bolts should be set
20 according to the strength of the magnetic field and the practical structure, and too many bolts will make the adjusting difficult. It is not difficult for those ordinarily skilled in the art to change and adjust those bolts according to the specific cases to achieve the shimming effect.

25 The operators could use one or a combination of the above-mentioned methods to achieve better shimming effect.

One An advantage of the apparatus and method of the present invention lies in is that the magnet made by the method of the present invention could have field strength higher than 0.3T with higher homogeneity in the scanning area satisfying the requirements. Therefore, the size of the apparatus could be
30 reduced and the cost will be reduced. For example, the specifications of the

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magnet of 0.35T manufactured according to the present invention are as follows: the weight is less than 16 tons, the uniformity of the magnetic field in 36cm sphere is less than 40ppm; and the width of the patient gap is larger than 41cm and the stability of the static magnetic field is <±20Hz/10 minutes.

- 5 ~~Another advantage of the apparatus and method of the present invention is that since the apparatus could be precisely designed and adjusted, most shimming works could be finished during the processing of manufacturing and assembling of in factory and it is unnecessary to carry out passive shimming at site and thus saves the time for installation.~~
- 10 Although modifications and changes may be suggested by those skilled in the art, it is the invention of the inventors to embody within the patent warranted heron all changes and modifications as reasonably and properly come within the scope of their contribution to the art.